

**BELLCOMM, INC.**

1100 Seventeenth Street, N.W. Washington, D. C. 20036

**SUBJECT:** Description of the Apollo VHF  
Ranging System - Case 320

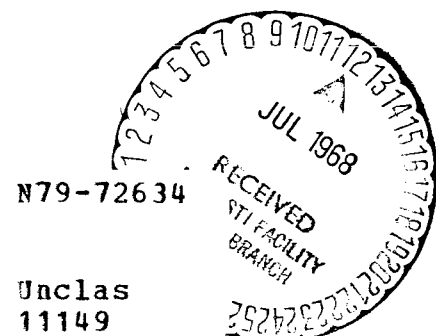
**DATE:** April 5, 1968

**FROM:** K. H. Schmid

ABSTRACT

The Apollo VHF ranging system consists of a Digital Ranging Generator aboard the Command and Service Module, a Range Tone Transfer Assembly aboard the Lunar Module, and VHF transceivers to establish the two-way communications link between the two vehicles. This memorandum describes the operation of the ranging system as it is presently being implemented. Voice operation of the system is not treated explicitly in this description.

(NASA-CR-95421) DESCRIPTION OF THE APOLLO  
VHF RANGING SYSTEM (Bellcomm, Inc.) 24 p



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**RESEARCH**

**BELLCOMM, INC.**

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**SUBJECT:** Description of the Apollo VHF  
Ranging System - Case 320**DATE:** April 5, 1968**FROM:** K. H. SchmidMEMORANDUM FOR FILEI. Introduction

In the planned mission configuration the Apollo Lunar Module (LM) will be required to rendezvous with the orbiting Command and Service Module (CSM). Optical techniques, and an X-band radar having range, range rate and angle readouts aboard the LM, will be used to accomplish the rendezvous. In an emergency, however, the CSM may be required to rendezvous with the LM. A VHF ranging system, providing a range readout aboard the CSM is being developed to add this capability to the overall system. The purpose of this memorandum is to describe this system as it presently exists.<sup>1</sup>

The new ranging system consists of a Digital Ranging Generator (DRG) which is to interface with a modified VHF transceiver aboard the CSM (see Figure 1) and a Range Tone Transfer Assembly (RTTA) which is to interface with a similar transceiver aboard the LM (see Figure 2). The transceivers will be used to establish the two-way communications link between the LM and CSM.

The DRG generates coarse (low frequency), mid (medium frequency), and fine (high frequency) square wave tones which are used to ON-OFF key (100% AM) the CSM transmit carrier. Tones are selected according to a particular sequence most suitable for acquisition and lock-up of the ranging system; the sequential selection of tones is performed automatically in the DRG.

The LM VHF ranging transponder, consisting of the VHF transceiver and the RTTA, receives and detects the tones from the CSM. It should be noted that the coarse tone is added (modulo-2) to the mid tone when the coarse tone is transmitted over the VHF links; this combined tone is referred to as the mid and coarse tone. If a mid tone or mid and coarse tone is detected at the LM, it is simply remodulated on the return VHF link to the CSM. If the fine tone is received at the LM, however, a fine tone tracking loop in the RTTA is employed to regenerate the fine tone prior to modula-

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<sup>1</sup>"Apollo VHF Ranging Critical Design Review," RCA, Camden, New Jersey, February 28 - March 1, 1968.

tion of the return link to the CSM. By using this narrow band loop to phase lock the local voltage controlled crystal oscillator (VCXO) to the received fine tone signal, a relatively noise-free fine tone, which is coherent with the received fine tone, can be generated for transmission to the CSM.

The DRG compares the phase between its transmitted tones and the tones received from the LM. The DRG derives the range number from this comparison and presents a range readout to the external display and computer. A maximum unambiguous range of 327 n. miles is attainable using the DRG.

In addition to the ranging alone mode described above, the new system provides a voice plus ranging mode. Simultaneous voice and ranging is achieved by clipping the voice in the keyer and using the resultant bipolar waveform to gate the ranging fine tone on and off. Voice transmission is not allowed while the mid tone or mid and coarse tone is being transmitted during the acquisition phase of the ranging sequence.

Voice plus ranging operation degrades the receive voice and ranging SNRs; however, the theory of operation of the DRG and RTTA remains the same. Thus, no differentiation between these two modes is considered for the purposes of describing the ranging system.

## II. Digital Ranging Generator (DRG)

### A. Range Tone Generator

As shown in Figure 3, three basic ranging tone frequencies are derived in a 13-stage divider chain which, in turn, is driven by a stable range clock. The basic square wave tone frequencies are tabulated below.

Table I. Basic Tone Frequencies

Fine Tone	31.6kHz
Mid Tone	3.95kHz
Coarse Tone	247Hz

Note that the fine tone is delayed prior to transmission. Detection of the mid tone or the mid and coarse tone (at the LM and CSM) is performed at the receiver envelope detector which follows the IF, while detection of the fine tone occurs at the receiver gate which precedes the IF. The addi-

tional delay of the fine tone incurred at the range tone generator is required so that total round trip equipment delay is the same for all three tones.

Before transmission, the coarse tone is added (modulo-2) to the mid tone; this is equivalent to 1/2 cycle phase modulation of the mid tone by the coarse tone. By using this PM technique it is possible to send both the mid and coarse frequencies simultaneously. This feature offers considerable advantage when locking-up the receive portion of the ranging system. The tones available for transmission are shown below.

Table II. Transmit Tone Frequencies

Fine Tone	31.6kHz
Mid Tone	3.95kHz
Coarse and Mid Tone	247 Hz $\oplus$ 3.95 kHz

Each of the tones is selected according to the predetermined sequence in the programmer. Operation of the tone select switch is controlled by the programmer; the selected tone keys the transmitter ON-OFF. Timing for the programmer is provided by a 247 Hz signal from the divider chain.

The sequence and time duration of the tones have been chosen to allow for proper acquisition and tracking of the ranging tones in the RTTA and DRG. The programmer sequence, and functions performed by the system during each time interval, are shown in Table III. It should be noted that the system will be cleared automatically if range rate in excess of 1900 ft/sec occurs, or if proper acquisition of the ranging tones during the allotted time interval is not achieved. Once the system is cleared, manual re-start of the ranging sequence is necessary if additional range measurements are desired.

## B. Three Tone Tracker

### 1. General

The three tone tracker consists of a 13-stage divider chain similar to the divider chain in the range tone generator (see Figure 1). The tracker is driven by the same range clock signal. Pulse logic and phase lock loops are integrated with the divider chain such that the basic tone frequencies generated in the divider can be aligned in-phase with the received ranging tones. The pulse logic can shift the phase of the tracker generated tones by adding or deleting pulses to the divider chain until an in-phase condition occurs. A delay line provides vernier adjustment of

Table III. RANGING TONE SEQUENCE

<u>SEQUENCE</u>	<u>ACTIONS</u>	<u>XMIT</u>	<u>TRACK</u>	<u>APPROXIMATE TIME</u>
1. MANUAL START	RESET DISPLAY START SEQUENCE PROGRAMMER WITHDRAW DATA GOOD	--	--	2 SEC
2. MID TONE ACQUISITION		MID TONE	MID TONE	2 SEC
2a. ACQUISITION GOOD TRACK TEST		MID TONE	MID TONE	
3. COARSE ACQUISITION	MID TONE LOOP COASTS	MID AND COARSE TONE	COARSE TONE	2 SEC
4. MID AND COARSE TONE TRACK		MID AND COARSE TONE	MID AND COARSE TONE	2 SEC
4a. ACQUISITION GOOD TRACK TEST		MID AND COARSE TONE	MID AND COARSE TONE	
5. LM LOOP LOCK-UP	MID TONE LOOP COASTS	FINE TONE		2 SEC
6. FINE TONE ACQUISITION		FINE TONE	FINE TONE	2 SEC
7. DATA GOOD TEST	TEST FOR DATA GOOD, FINE TONE LOOP COASTS	FINE TONE	--	80 MSEC
8. FINE TONE TRACK	READ OUT TO DISPLAY GO TO INCREMENTAL UPDATE	FINE TONE	FINE TONE	2 SEC
9. DATA GOOD TEST	TEST FOR DATA GOOD, FINE TONE LOOP COASTS	FINE TONE	--	80 MSEC
10. FINE TONE TRACK	READY FOR READ OUT TO COMPUTER	FINE TONE	FINE TONE	
11. REPEAT STEPS 9 AND 10				

the phase such that a resolution of 0.01 n. mile is attainable. Once the tones have been acquired, range can be determined by comparing the digital readout of the tracker divider state to the digital readout of the range tone generator divider state; this is accomplished in the data output portion of the DRG.

The acquisition and tracking process is described step-by-step below according to the sequence of tones received by the tracker.

## 2. Mid Tone Tracking Loop

As shown in Table III the tracker first receives the mid tone for a period of 2 seconds. Refer to Figure 4 for a diagram of the mid tone loop. Acquisition and track of the mid tone is accomplished as follows.

The received mid tone from the receiver envelope detector is the reference input to the product detector. The 3.95 kHz Q signal from the tracker divider is selected by the programmer to be the second input to the product detector. Initially the tracker signal is at some arbitrary phase angle with respect to the reference.

The product detector acts as a phase detector for the above two signals. A DC error voltage is produced at the output of the low pass filter. The polarity and magnitude of the error voltage correspond to the phase difference between the two signals.

The DC-to-pulse converter produces pulses at a rate proportional to the magnitude of the error voltage. If the error voltage is of one polarity, pulses are generated at an output which increases the setting of the forward-backward (FB) counter. If the error voltage is of the opposite polarity, pulses are generated at an output which decreases the setting of the FB counter.

If the FB counter overflows in the "forward" direction the pulse logic inserts an extra pulse between the clock pulses at the input to the tracker divider chain. The effect of the extra pulse is to advance the output waveforms by 0.49 $\mu$  sec. in time (one clock period). If the FB counter overflows in the "backward" direction the pulse logic deletes a clock pulse at the input to the tracker divider chain. The effect of the deleted pulse is to delay the output waveforms by 0.49 $\mu$  sec.

Thus the phase of the mid tone generated by the tracker is adjusted toward an in-phase condition with respect to the received mid tone. Proper lock of the loop occurs when the 3.95 kHz Q signal is in quadrature with the reference mid tone; at this time no error voltage is produced and the loop will remain in a quiescent condition. Thus the tracker 3.95 kHz I signal (which is  $90^\circ$  out of phase with the 3.95 kHz Q signal) is in-phase with the received mid tone.

It should be noted that a false lock condition could occur i.e. the 3.95 kHz Q signal could lock-up  $180^\circ$  from the proper lock-up point. While this is an unstable lock-up point due to the slope of the error characteristic, a false lock is possible when the initial arbitrary phase of the tracker is nearly  $180^\circ$  out of phase with the proper lock-up point, and when the system is "quiet" i.e. operating under high signal-to-noise conditions. Under these conditions zero loop error voltage is produced. An ambiguity indicator and good track detector (see Figure 5) are provided to aid in preventing false lock-up of the loop and to verify correct lock respectively. The ambiguity indicator contains a negative threshold detector used as an acquisition aid for acquiring the coarse and mid tones. The good track detector contains a positive threshold detector used for good track verification of all tones.

The acquisition aid for mid tone loop lock-up is shown in Figure 5. The reference signal input to the product detector is the 3.95 kHz received signal. During the initial portion of the mid tone acquisition period, the programmer selects the 3.95 kHz I signal as the input to the product detector. The product detector acts as a coherent amplitude detector for the 3.95 kHz I tracker signal and the received 3.95 kHz signal. If the two signals are nearly  $180^\circ$  out-of-phase at the start of the acquisition procedure, the ambiguity indicator receives a negative voltage from the coherent amplitude detector. If the negative voltage exceeds a certain negative threshold value, the ambiguity indicator sends a trigger pulse to the last divider stage of the mid tone loop. This adds  $180^\circ$  to the tracker mid tone phase; the tracker mid tone then should be near the correct lock-up point of the loop. The loop now can effect rapid acquisition of the mid tone. Thus, at the conclusion of the mid tone acquisition period, the 3.95 kHz I (tracker) tone should be in-phase with the received 3.95 kHz tone.

### 3. Acquisition Good Track Test (Mid Tone)

An acquisition good track test is performed during the final portion of mid-tone track to assure that the mid-tone loop is locked at the correct point. The good track test circuit is shown in Figure 5.

The programmer again selects the 3.95 kHz I tracker signal as one input to the product detector while the reference input is the received 3.95 kHz signal. The product detector acts as a coherent amplitude detector for the 3.95 kHz I tracker signal and the 3.95 kHz received signal.

If the two mid tone signals are in-phase, a positive voltage is produced which exceeds the positive threshold setting of the good track detector. This results in a good track output signal to the programmer and the acquisition sequence is allowed to continue.

If the two mid tone signals are 180° out-of-phase (false lock) a negative voltage is produced which cannot exceed the positive threshold setting of the good track detector. Thus, a good track signal is not generated and the system is cleared.

Therefore, correct operation of the mid tone tracking loop results in a 3.95 kHz I signal which is in-phase with the receive mid tone in the given acquisition time of 2 seconds. If the phase resolution of the product detector is good, the last six stages of the divider in the mid tone loop are set correctly. The first three stages and the delay line setting providing the least significant bits of range information, must be resolved using the fine tone loop as discussed later.

### 4. Coarse Tone Tracking Loop

As noted in Table III the mid and coarse tone is transmitted for a 2 second period to allow for lock-up of the coarse tone loop. Refer to Figure 6 for a diagram of the coarse tone loop. Note that the 4 divider stages in this loop were not adjusted during mid tone acquisition since these stages are not within the mid tone loop. Thus, the tracker 247 Hz Q signal is at some arbitrary phase with respect to the received 247 Hz signal.

During this 2 second time interval the programmer selects the 247 Hz Q  $\oplus$  3.95 kHz I signal as one input to the product detector. The reference signal input is the receive

247 Hz  $\oplus$  3.95 kHz signal. Since the 3.95 kHz I signal is in-phase with the 3.95 kHz receive signal due to the preceding mid tone acquisition procedure, the product detector acts as a phase detector for the 247 Hz Q signal and the received 247 Hz signal. The coarse tone loop responds to an error voltage in the same manner as the mid tone loop.

The acquisition aid for coarse tone loop lock-up is shown in Figure 5. The reference signal input to the product detector is the 247 Hz  $\oplus$  3.95 kHz received signal. During the initial portion of the coarse tone acquisition period, the programmer selects the 247 Hz I  $\oplus$  3.95 kHz I signal as the input to the product detector. Since the 3.95 kHz I signal is in-phase with the 3.95 kHz received signal, the product detector acts as a coherent amplitude detector for the 247 Hz I tracker signal and the received 247 Hz signal. If the two signals are nearly 180° out-of-phase at the start of the acquisition procedure, the ambiguity indicator sends a trigger pulse to the last divider stage of the coarse tone loop. This adds 180° to the tracker coarse tone phase; the tracker coarse tone then should be near the correct lock-up point of the loop. The loop now can effect rapid acquisition of the coarse tone. Thus, at the conclusion of the coarse tone acquisition period, the 247 Hz I tracker tone should be in-phase with the received 247 Hz tone.

Any coarse tone loop correction pulses during the final portion of the acquisition period result in clearing of the system. Correction pulses indicate that the loop is still hunting at the end of the time interval allotted for acquisition.

#### 5. Mid and Coarse Tone Track

The mid tone loop is re-enabled and the mid tone loop and coarse tone loop track the received mid and coarse tone for the succeeding 2 second period. This period allows for updating of the mid tone loop which is required if range has changed during the preceding 2 second coarse tone acquisition period. At the conclusion of this simultaneous track the 4 divider stages of the coarse tone loop and the last 6 divider stages of the mid tone loop should be set correctly. Thus, the last 10 divider stages of the tracker divider chain, as shown in Figure 1, should be set correctly.

## 6. Acquisition Good Track Test (Coarse Tone)

An acquisition good track test is performed during the final portion of the mid and coarse tone track period to assure that the coarse tone is locked at the correct point. Again, the good track detector (see Figure 5) is used for this test.

The programmer selects the 247 Hz I  $\oplus$  3.95 kHz I tracker signal as one input to the product detector; the reference input is the received 247 Hz  $\oplus$  3.95 kHz signal. Since the 3.95 kHz I signal is in-phase with the received 3.95 kHz signal, the product detector acts as a coherent amplitude detector for the 247 Hz I tracker signal and the 247 Hz receive signal.

If the two coarse tones are in-phase, a positive voltage is produced which exceeds the positive threshold setting of the good track detector. This results in a good track output signal to the programmer and the acquisition sequence is allowed to continue.

If the two coarse tones are 180° out of phase (false lock), a negative voltage is produced which cannot exceed the positive threshold setting of the good track detector. Thus, a good track signal is not generated and the system is cleared.

## 7. Fine Tone Tracking Loop

In order to set the first few stages of the divider tracker chain and the delay line, the programmer selects the fine tone for transmission. An initial period of 2 seconds is allocated for lock-up of the LM fine tone tracking loop (see Section III). At the end of this period, the programmer enables both the CSM receiver gate and the tracker fine tone loop. The succeeding 2 seconds are allocated for acquisition of the tracker fine tone loop; the loop is shown in Figure 7.

The fine tone loop operates in a considerably different fashion from the mid or coarse tone loops. Since the fine tone frequency may not pass through the IF filter, phase detection of the fine tone must precede the IF. This is accomplished by phase modulating the 31.6 kHz I signal from the tracker by  $+ 1/16$  cycle at a switching frequency of 5.27 kHz. This locally generated reference signal passes through the delay line to the receiver where it is used to gate the received fine tone on and off.

The gating process produces a 5.27 kHz error signal amplitude modulated on the IF. Provided the phase difference is small, the amplitude of the error signal is proportional to the phase difference between the received fine tone and the mean phase of the tracker fine tone. The error signal passes through the IF filter and is demodulated at the envelope detector. The amplitude of the 5.27 kHz error signal, which is indicative of the phase error as explained above, is obtained by coherent amplitude detection at the fine tone loop product detector. A 5.27 kHz coherent signal from the tracker is used as the reference input to the product detector. The output of the detector and low pass filter is an error voltage proportional to the phase error between the tracker and received fine tones.

The DC-to-pulse converter, FB counter and pulse logic operate in the same fashion as in the mid tone loop. One exception is that the pulse rate/volt is much lower for the fine tone loop. In attempting to correct the phase of the tracker fine tone, the taps of the delay line are switched over the full range of four taps before the pulse logic is activated to add or delete a clock pulse. Once the pulse logic is activated, the delay line tap setting reverts to its original state. This process is repeated until the phase error between the tracker and received fine tones can be compensated entirely by the delay line. Thus, when the error voltage is reduced to zero, the divider stages of the fine tone loop and the delay line tap are set correctly so that the tracker fine tone is in-phase with the received fine tone.

#### 8. Data Good Test (Fine Tone)

In order to verify that the received fine tone is still present and that false lock of the fine tone has not occurred, a data good test of the fine tone is performed upon command from the programmer. The data good test configuration is shown in Figure 5.

As a first step the programmer disables the fine tone tracking loop. The tracker 31.6 kHz Q fine tone signal then is selected for  $\pm 1/16$  cycle phase modulation at the early/late gate. Since this signal is  $90^\circ$  out-of-phase with the 31.6 kHz I signal used for locking up the fine tone loop, a maximum amplitude error signal at 5.27 kHz is generated at the output of the receiver gate.

The programmer selects the 5.27 kHz reference input to the product detector as shown in Figure 5. The amplitude of the error signal is coherently derived at the product detector.

If the tracker fine tone is correctly locked to the receive fine tone a positive DC voltage is generated at the output of the low pass filter. The voltage exceeds the positive voltage threshold setting of the good track detector. This results in a good track output signal to the programmer and a data good signal to the computer.

If the tracker fine tone is false locked to the received fine tone, a negative DC voltage is generated at the output of the low pass filter and thus the positive voltage threshold setting of the good track detector cannot be exceeded. Since a good track signal is not generated in the allotted time interval the system is cleared, and re-start of the acquisition sequence is necessary.

### C. Data Output

Once the fine tone loop is properly tracking, the data output portion of the DRG (see Figure 1) can feed range data to the external display and computer. First the internal display counter and computer output register are cleared. The state of the range tone generator 13-stage binary divider chain is continually monitored by the recognition gate. When the 13-stage binary divider chain passes through a particular state, i.e. a predetermined 13 bit sequence which allows for subtraction of coarse equipment delay, the recognition gate pulses the transfer gate. The state of the tracker divider chain (15 bits) is sampled at this instant provided the transfer gate receives a command from the programmer.

The sampled data is fed to the internal display counter where the range number is down counted to subtract fine equipment delay. Thus, the actual range number corresponding to round trip propagation time is stored in the internal display counter. A data good test is performed at this time. Provided the test result is satisfactory, the range number is "dumped" at a 31.6 KBPS rate via the display output to the external display where it is presented visually. Each output pulse to the display corresponds to a 0.01 n. mile range increment. The external display is up-dated by incremental display pulses derived from the fine tone tracking loop.

A data good signal is then sent to the computer to initiate range readout to the computer. Upon receipt of a computer range strobe, the data output circuitry of the DRG is activated. The internal display down counter and computer output register are cleared. A range number (15 bits) from the tracker is transferred to the internal display counter in accordance with the procedure described above. Again the range number is down-counted to subtract fine equipment delay.

The actual range number is then transferred to the computer output register. A data good test is performed at this time. Provided the test result is satisfactory the command readout from the computer, consisting of 15 pulses at a 3.2 kbps rate, clocks out the 15 bits of range data to the computer. This process is repeated at a rate of one measurement per minute to provide range readout data to the computer.

### III. Range Tone Transfer Assembly (RTTA)

The LM VHF ranging transponder consists of the VHF transceiver and RTTA (see Figure 2). Two transponder loops are provided in the RTTA. One loop is utilized to detect and reshape either the mid tone or the mid and coarse tone for keying the LM transmitter. The other loop is utilized to phase lock a locally generated fine tone to the received fine tone so that a relatively noise-free fine tone can be transmitted on the return link to the CSM.

Selection of the proper loop and activation of the early/late gate in the LM ranging transponder are controlled by the signal sensor as summarized in Table IV.

Table IV Signal Sensor Logic Functions

<u>LM Receives</u>	<u>Loop Select</u>	<u>Early/Late Gate</u>
No Ranging Tone	Fine	Activate
Mid Tone	Mid	De-activate
Mid and Coarse Tone	Mid	De-activate
Fine Tone	Fine	Activate

Prior to reception of ranging tones at the LM, the signal sensor does not detect energy at the 3.95 kHz frequency. The signal sensor activates the LM receiver early/late gate and selects the locally generated fine tone for modulation of the link to the CSM (see Table IV) in order to maintain the 50% RF duty cycle. Since transmission of ranging tones to the LM and acquisition of these tones has not been initiated at the CSM, the DRG ignores the received fine tone from the LM and erroneous range data is not produced.

Once the acquisition sequence is initiated at the CSM, the LM first receives the mid tone for a period of 2 seconds (see Table III). Despite the effect of the active LM

receiver gate, the signal sensor detects energy at the 3.95 kHz mid tone frequency. The sensor performs the logic shown in Table IV. Thus, the mid tone is simply reshaped and transmitted to the CSM.

The mid and coarse tone is received at the LM for the succeeding 4 second interval. Since a large portion of the signal energy can pass the 3.95 kHz filter, the signal sensor maintains the existing configuration during this time interval as shown in Table IV. Thus, the mid and coarse tone is reshaped and repeated on the return link to the CSM.

At the conclusion of this interval the fine tone is received at the LM. The signal sensor no longer detects energy at 3.95 kHz, and it therefore activates the early/late gate and selects the locally generated fine tone for transmission to the CSM. The gate derives an error signal in the exact manner as that described in Section II. Since the locally generated fine tone frequency is slightly different from the received fine tone frequency a period of 2 seconds is allowed for lock-up of the LM fine tone tracking loop in the RTTA. Due to the difference in frequency, the two waveforms gradually drift into an in-phase condition. When this occurs, the tracking loop error signal phase locks the locally generated fine tone to the receive fine tone. Thus, a coherent system is established to regenerate the fine tone at the LM.

At the conclusion of this time interval, the DRG programmer in the CSM enables the DRG fine tone tracking loop. If the RTTA loop, in fact, is locked up, the DRG fine tone tracking loop can lock-up correctly and valid range data can be obtained.

If the RTTA loop did not lock up during its allocated time interval, its transmitted fine tone frequency is not coherent with the DRG tracker fine tone frequency. This condition causes an excessive rate of correction pulses to be generated in the DRG fine tone tracking loop as it attempts to track the received non-coherent fine tone. An excessive rate of correction pulses, which would be interpreted as a large range rate, results in automatic clearing of the system (see Section II) and the acquisition sequence must be re-initiated to obtain range data.

IV. Concluding Remarks

The system description presented in this memorandum attempts to delineate the gross operation of the Apollo VHF ranging system as it is presently conceived. Additional information on the theory of operation of this system is available from the author.

*K. H. Schmid*

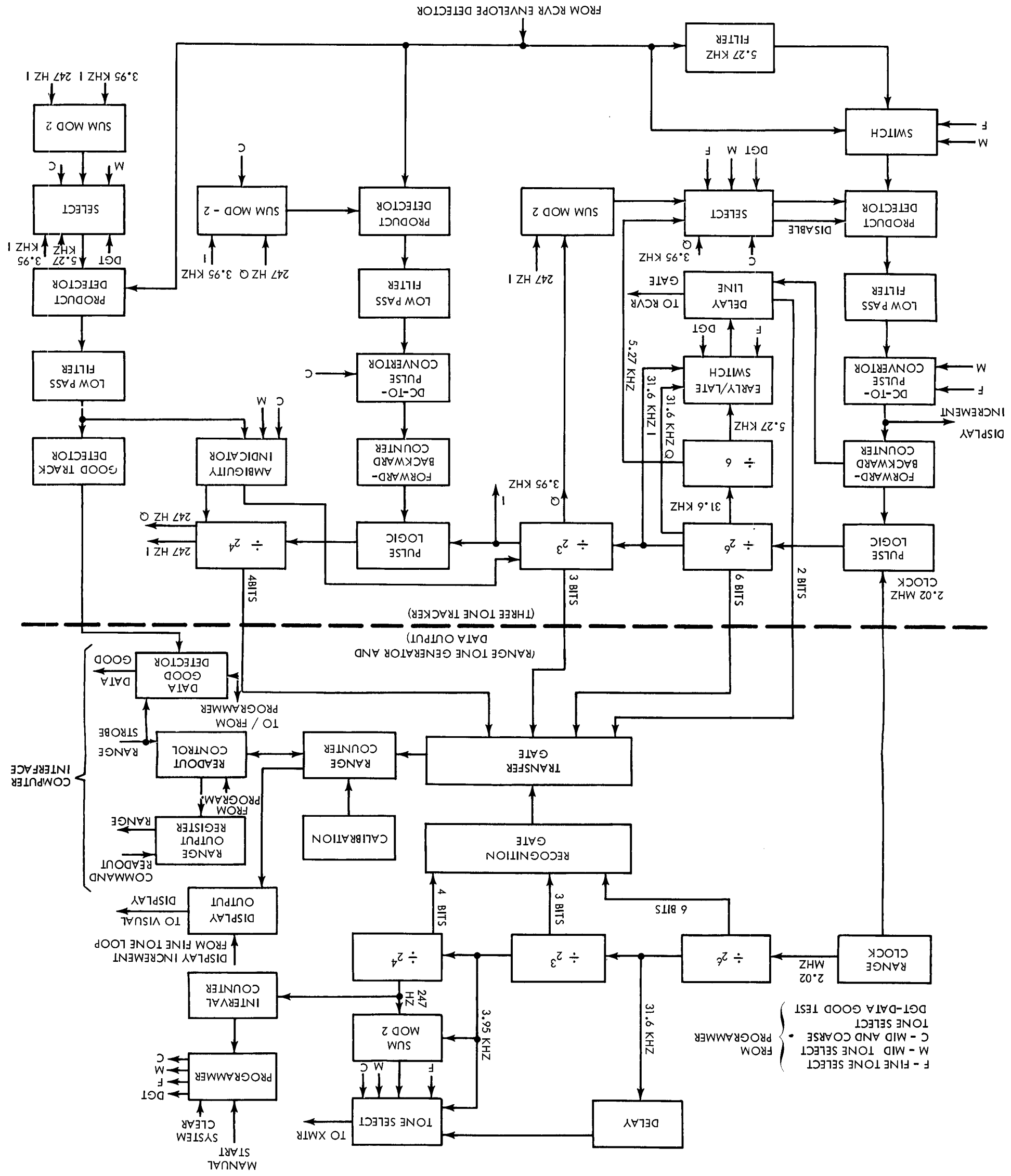
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K. H. Schmid

Attachment

Figures 1 through 7

FIGURE 1 - DIGITAL RANGING GENERATOR



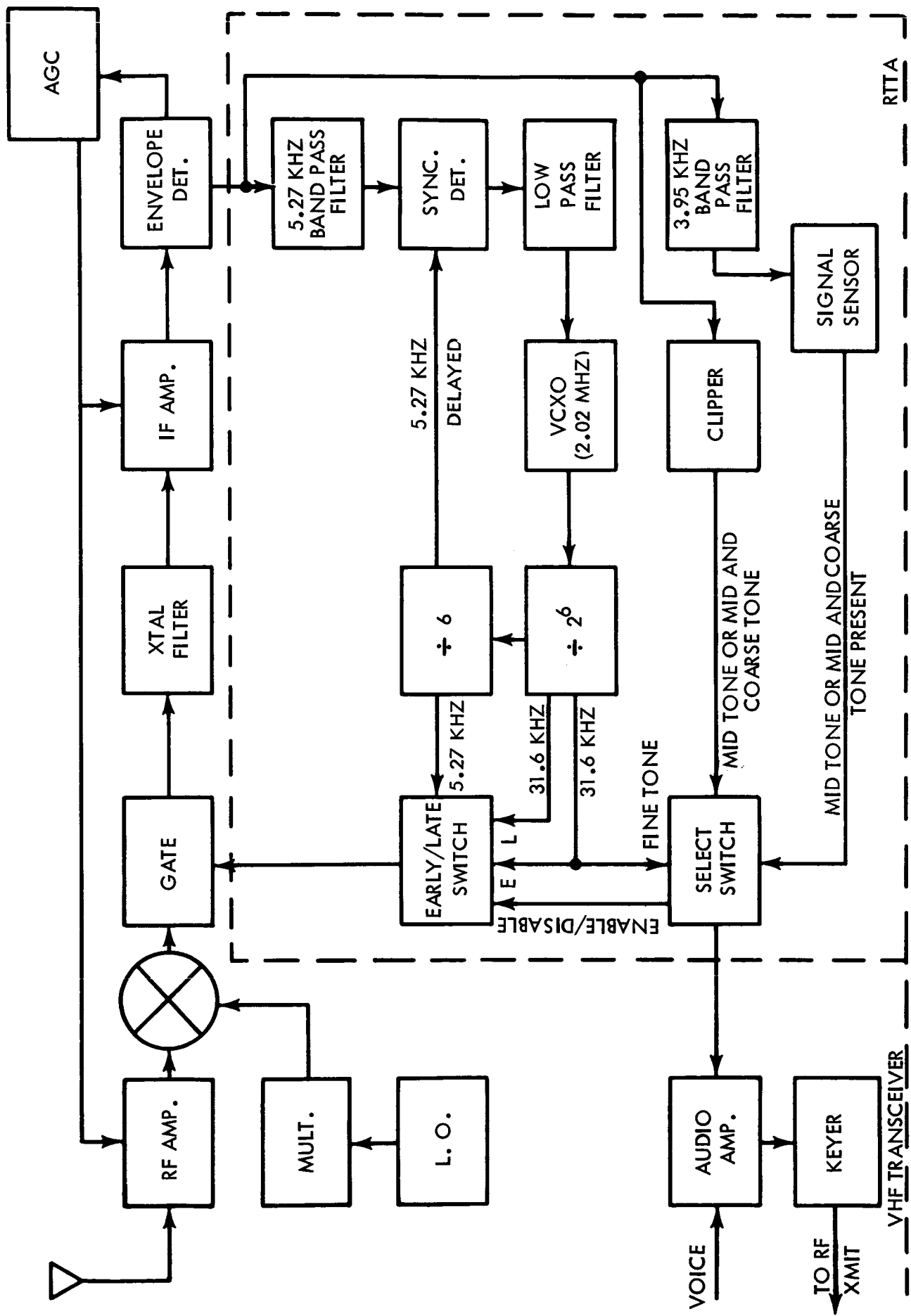
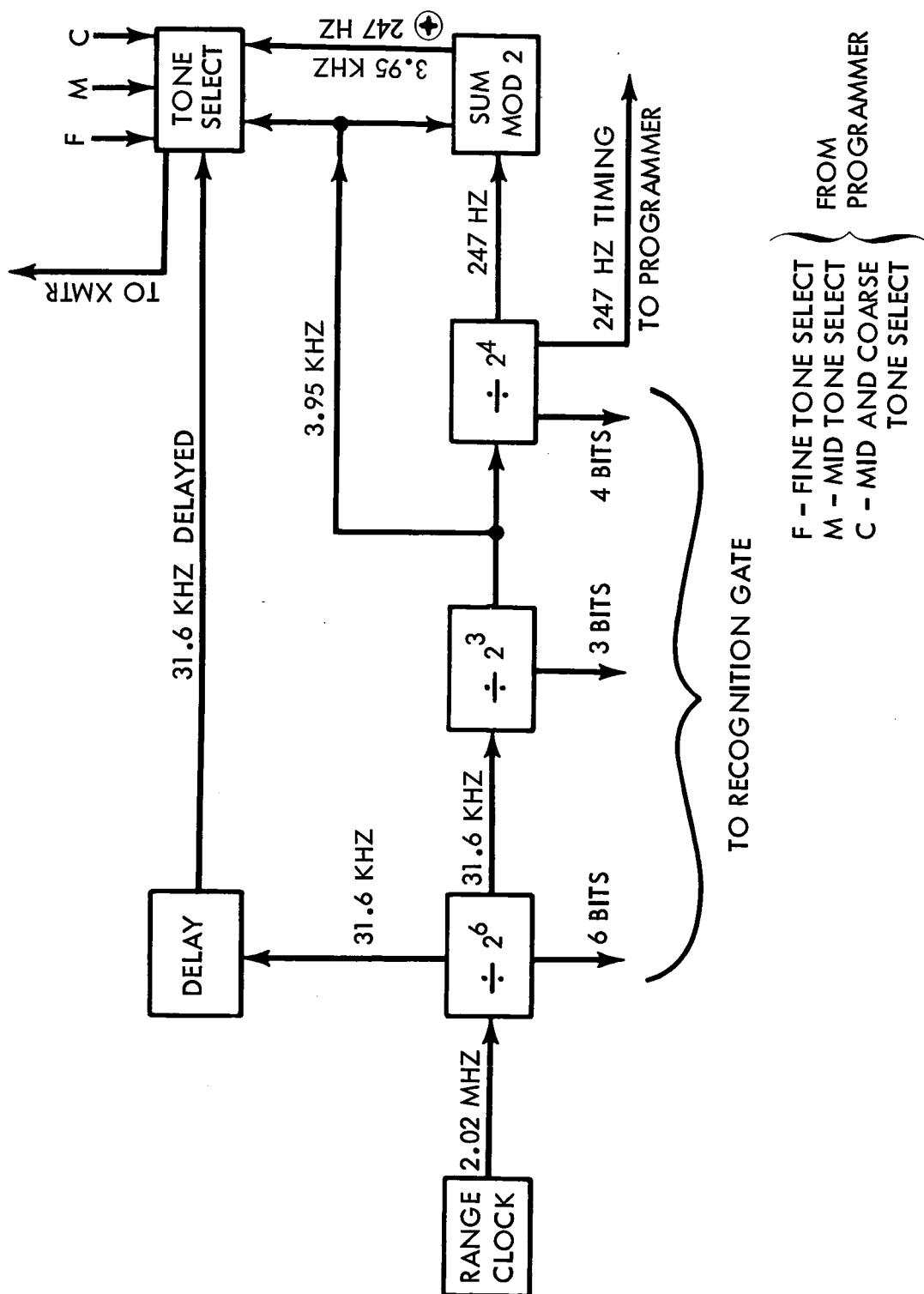


FIGURE 2 - LM RANGING TRANSPONDER.



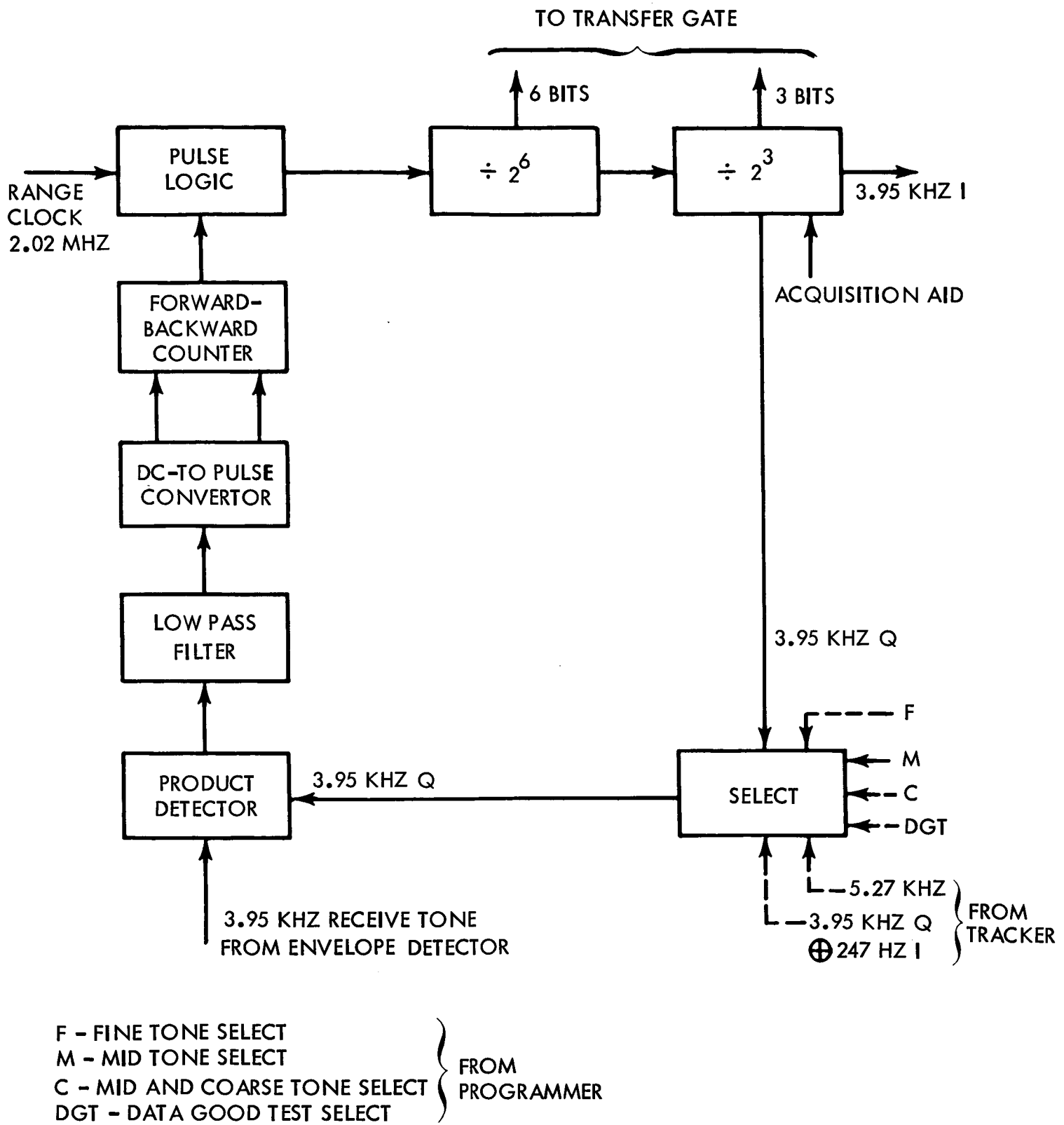
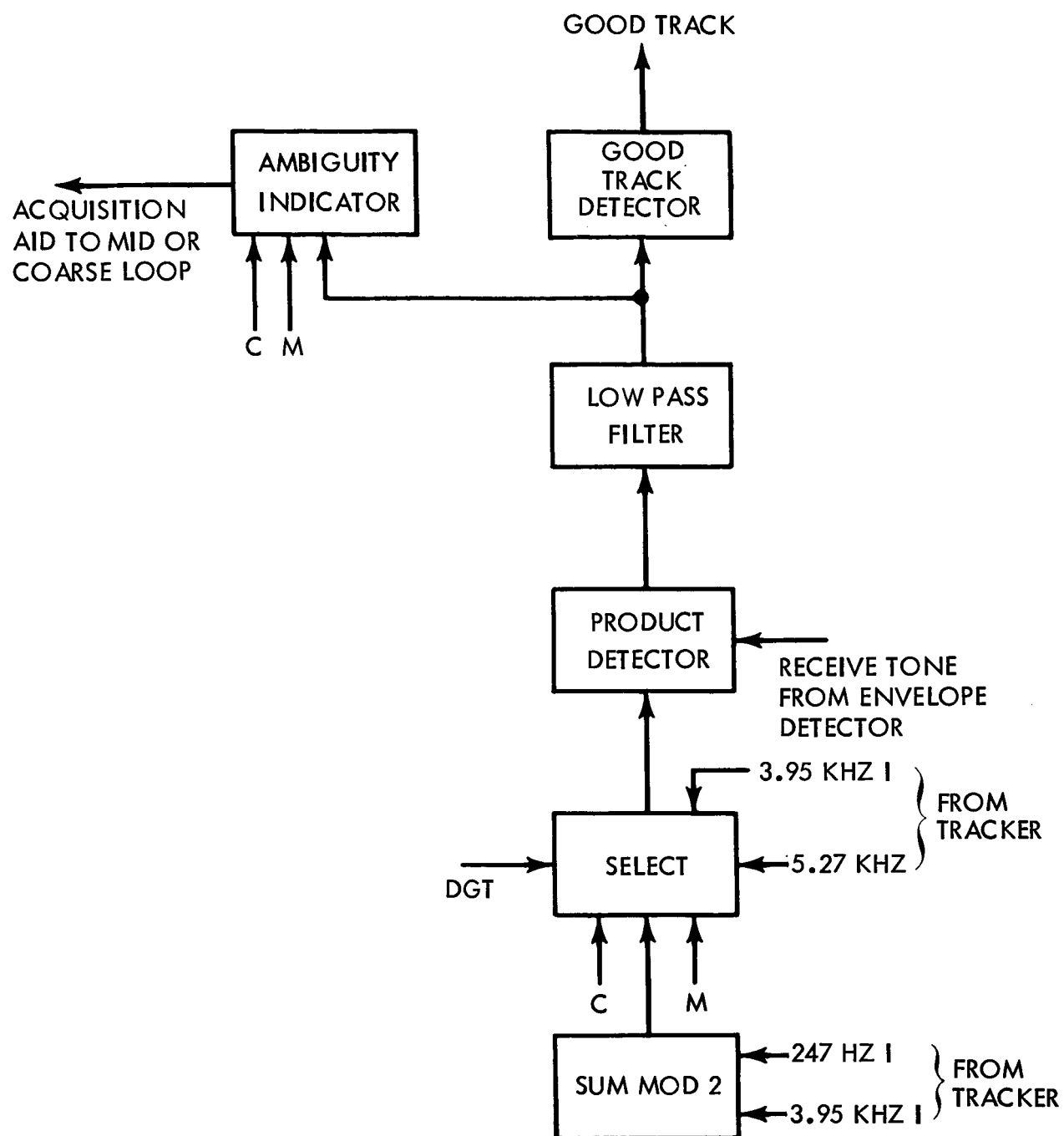


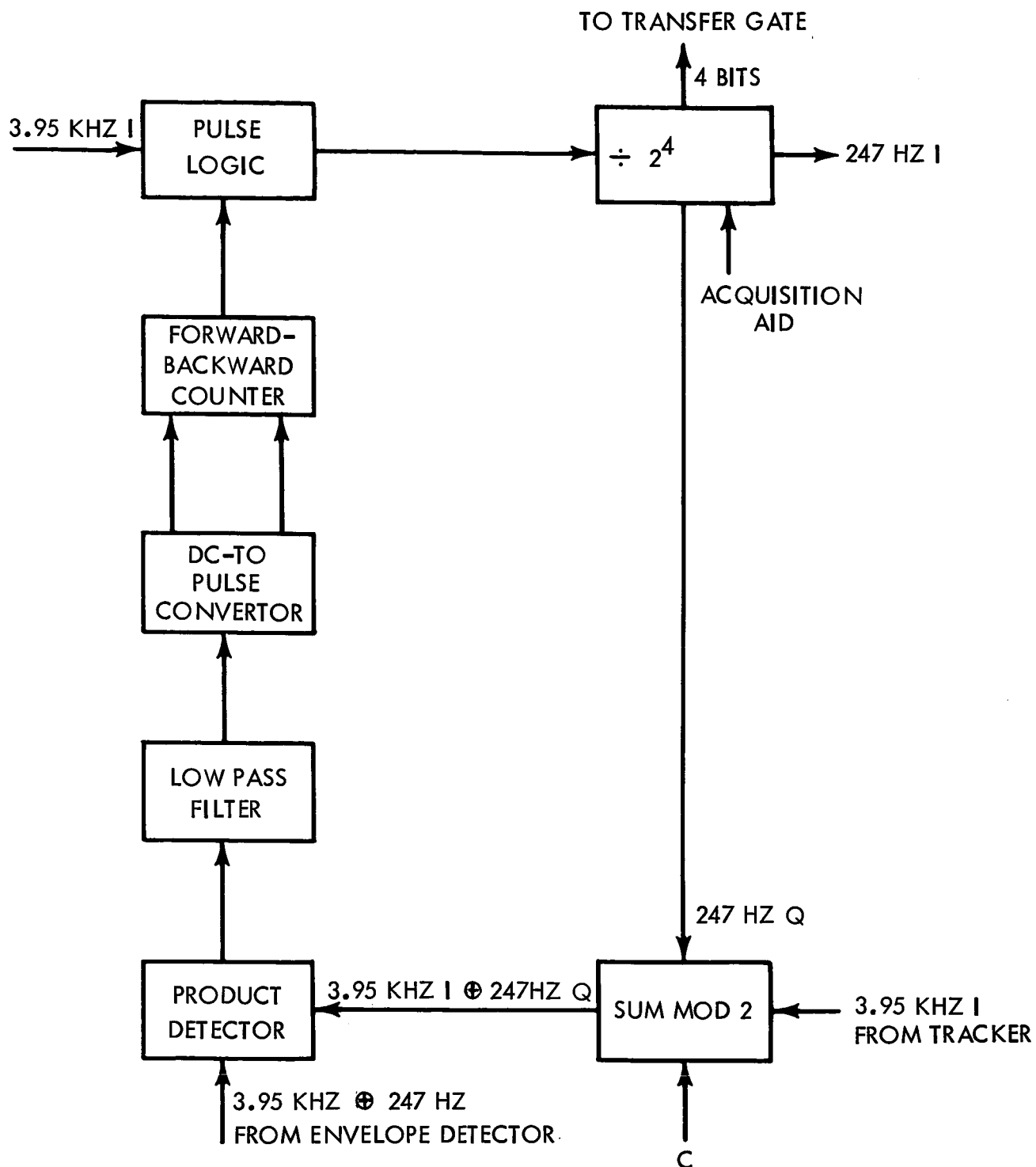
FIGURE 4 - MID TONE TRACKING LOOP



M - MID TONE SELECT  
 C - MID AND COARSE TONE SELECT  
 DGT - DATA GOOD TEST SELECT

FROM PROGRAMMER

FIGURE 5 - AMBIGUITY INDICATOR AND GOOD TRACK DETECTOR.



C - MID AND COARSE TONE ENABLE ( FROM PROGRAMMER).

FIGURE 6 - COARSE TONE TRACKING LOOP.

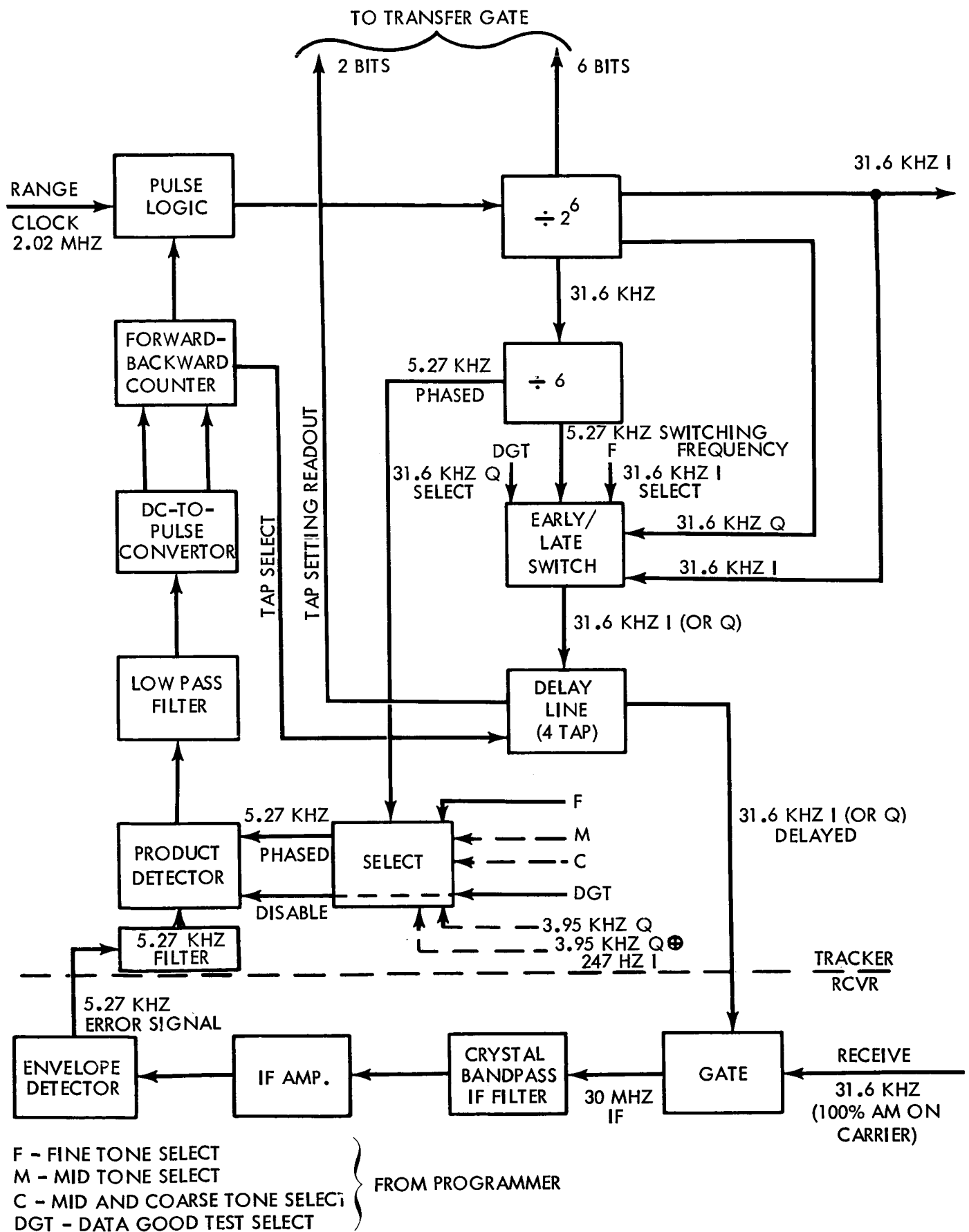


FIGURE 7 - FINE TONE TRACKING LOOP.

# BELLCOMM, INC.

Subject: Description of the Apollo VHF  
Ranging System

From: K. H. Schmid

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